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PART 1

Limits for Intakes of Radionuclides by Workers

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RADIATION PROTECTION

ICRP PUBLICATION 30

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Limits for Intakes of Radionuclides by Workers

A report of Committee 2 of the
International Commission on Radiological Protection

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PREFACE

In 1967 the Commission asked ICRP Committee 2 to prepare a new version of its report on Permissible Dose for Internal Radiation, which was issued in 1959 as ICRP Publication 2. It was recognized that the preparation of the report would depend heavily on the advice to be given by the task groups on reference man, on lung dynamics and on the radiosensitivity of the tissues in bone. Completion of the report also had to await a revision of the Commission's basic recommendations, now available as *ICRP Publication 26.*

The following were the members of ICRP Committee 2 preparing the final version of the report:

J. Vennart (*Chairman*); W. J. Bair; G. C. Butler; G. W. Dolphin (*Secretary*); L. E. Feinendegen; W. Jacobi; J. Lafuma; C. Mays; P. E. Morrow; P. V. Ramzaev; W. S. Snyder (died June 1977) and R. C. Thompson.

In addition, the following were members of the committee during earlier stages of discussions about the report:

B. Chr. Christensen; M. Dousset; M. Izawa; J. Liniecki; L. D. Marinelli; W. G. Marley; K. Z. Morgan; J. Müller; V. Shamov and C. G. Stewart.

Committee 2 wishes to record its appreciation of the work of N. Adams and M. C. Thorne who materially assisted in the collection of data and in the preparation of this report, and to thank Mrs E. Henry and Mrs J. Rowley for secretarial assistance and great forbearance during the preparation of several drafts.

The dosimetric calculations have been the responsibility of a task group, originally working under the chairmanship of W. S. Snyder and latterly Mrs M. R. Ford, as follows:

W. S. Snyder (died June 1977); S. R. Bernard; L. T. Dillman (since May 1977); Mrs Mary R. Ford; J. W. Poston and Mrs Sarah B. Watson.

Committee 2 wishes to record its indebtedness to the task group and particularly to Mrs Ford for completing this exacting task under the very difficult circumstances following Dr Snyder's untimely death.

APPRECIATION

W. S. SNYDER

The Commission wishes to record its special indebtedness to the late W. S. Snyder for his unsparing work in the preparation of this and many other ICRP reports. The work of Dr Snyder for Committee 2 in particular and for the advancement of radionuclide dosimetry in general was legendary even in his own life-time. He was tireless in his efforts and always willing to impart his great store of knowledge both to his immediate colleagues and to students and specialists throughout the world. With his passing we lost not only an honoured and trusted colleague but also a friend.

GLOSSARY OF TERMS

Absorbed Fraction (AF)
: the fraction of energy emitted as a specified radiation type in a specified source tissue which is absorbed in a specified target tissue.

Activity Median Aerodynamic Diameter (AMAD)
: the diameter of a unit density sphere with the same terminal settling velocity in air as that of the aerosol particle whose activity is the median for the entire aerosol.

Annual Limit on Intake (ALI)
: The activity of a radionuclide which taken alone would irradiate a person, represented by Reference Man, to the limit set by the ICRP for each year of occupational exposure.

becquerel (Bq)
: the special name for the SI unit of activity, $1 \text{ Bq} = 1 \text{ s}^{-1}$ ($\approx 2.7 \times 10^{-11}$ Ci).

Cells near bone surfaces (BS)
: those tissues which lie within 10 μm of endosteal surfaces and bone surfaces lined with epithelium.

Committed Dose Equivalent (H_{50})
: the total dose equivalent averaged throughout a tissue in the 50 years after intake of a radionuclide into the body.

Cortical Bone
: equivalent to "Compact Bone" in *ICRP Publication 20*, i.e. any bone with a surface/volume ratio less than 60 $\text{cm}^2 \text{ cm}^{-3}$; in Reference Man it has a mass of 4 000 g.

Deposition probability (in lung region)
: the fraction of the activity or mass of an inhaled aerosol which is deposited in a particular region of the lung.

Derived Air Concentration (DAC)
: equals the ALI (of a radionuclide) divided by the volume of air inhaled by Reference Man in a working year (i.e. $2.4 \times 10^3 \text{ m}^3$). The unit of DAC is Bq m^{-3}.

Derived Air Concentration for Submersion (DAC(Submersion))
: one two-thousandth of the time integral of the concentration of a radionuclide in air which over a working year would alone irradiate a person to the limit specified by the ICRP.

Dose Equivalent (H)
: the product of the absorbed dose, the quality factor (Q) and the product of any other modifying factors (N). (currently $N = 1$.)

Dose-Equivalent Limits
: the maximum values of committed dose equivalent incurred in 1 year by individual organs (non-stochastic limits), and by the uniformly irradiated whole body (stochastic limit) of an occupationally exposed person, which are recommended in *ICRP Publication 26* (1977).

gray (Gy)
: the special name for the SI unit of absorbed dose. $1 \text{ Gy} = 1 \text{ J kg}^{-1} \equiv 100$ rad.

Lung Class (D, W or Y)
: a classification scheme for inhaled material according to its rate of clearance from the pulmonary region of the lung.

Non-stochastic effects

effects such as opacity of the lens of the eye for which the severity of the effect varies with the dose, and for which a threshold may therefore occur.

Quality Factor (*Q*)

the principal modifying factor (which depends on the collision stopping power for charged particles) that is employed to derive dose equivalent from absorbed dose.

Red Bone Marrow (active)

the component of marrow (assumed in this report to have a mass of 1 500 g) which contains the bulk of the haematopoietic stem cells.

Reference Man

a person with the anatomical and physiological characteristics defined in the report of the ICRP Task Group on Reference Man (*ICRP Publication 23*).

sievert (Sv)

the special name for the SI unit of dose equivalent. $1\ \text{Sv} = 1\ \text{J kg}^{-1} \equiv 100\ \text{rem}$.

Source Tissue (*S*)

tissue (which may be a body organ) which contains a significant amount of a radionuclide following intake of that radionuclide into the body.

Specific Absorbed Fraction

the fraction of energy emitted as a specified radiation type in a source tissue which is absorbed in 1 g of a target tissue.

Specific Effective Energy (SEE $(T \leftarrow S)_i$)

the energy (MeV), suitably modified for quality factor, imparted per gram of a target tissue (*T*) as a consequence of the emission of a specified radiation (*i*) from a transformation occurring in source tissue (*S*).

Stochastic Effects

malignant and hereditary disease for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose without threshold.

Target Tissue (*T*)

tissue (which may be a body organ) in which radiation is absorbed.

Trabecular Bone

equivalent to "Cancellous Bone" in *ICRP Publication 20*, i.e. any bone with a surface/volume ratio greater than $60\ \text{cm}^2\ \text{cm}^{-3}$; in Reference Man it has a mass of 1 000 g.

Transfer Compartment

the compartment introduced (for mathematical convenience) into most of the metabolic models used in this report to account for the delay between radioactive material entering body fluids and its deposition in particular tissues.

Weighted Committed Dose Equivalent ($w_T H_{50,T}$)

the product of the weighting factor and the committed dose equivalent for a specified tissue.

Weighting Factor (w_T)

the ratio of the stochastic risk arising from tissue *T* to the total risk when the whole body is irradiated uniformly.

CONTENTS

1. INTRODUCTION

The International Commission on Radiological Protection issued *ICRP Publication 2*, the report of Committee II on Permissible Dose for Internal Radiation, in 1959. Some changes and additional recommendations concerning individual radionuclides were subsequently made in *ICRP Publication 6* (1964) but no systematic revision of *ICRP Publication 2* has been published. The report has served as a satisfactory guide for the control of intakes of radionuclides into the body to meet the basic standards of the Commission, although there have been some misconceptions about its intent and some misuse of its recommendations. New information on the effects of radiation on the body, on the uptake and retention of radioactive materials in body tissues and better data on radioactive decay schemes have accumulated in the intervening period. These factors and changes in the basic recommendations of the Commission described in *ICRP Publication 26* have made it necessary for the Committee to publish a new report. In 1959, when the last report of Committee 2 was published, the existing recommendations of the Commission for occupational exposure were framed in terms of limits on the dose equivalent received by the organs and tissues of the body in any period of 13 weeks, with an additional restriction on the rate of accumulation of dose with age for the gonads, the blood-forming organs and the lenses of the eyes. Exposure of the individual was limited by the dose equivalent in the critical organ for which the ratio of the dose received to the dose limit was greatest (*ICRP Publication 1*, 1959 and Addendum, 1960). *ICRP Publication 2* recommended values of the maximum permissible concentration in air and in water (MPC) and of maximum permissible body burden (MPBB) for a number of radionuclides. For any radionuclide, continuous exposure of a Standard Man to either of the MPC values during the whole of a working life-time of 50 years would result in his containing the MPBB of the radionuclide at the end of that period. The MPBB was estimated to deliver a dose-equivalent rate in the appropriate critical organ such that the Commission's recommended limits on dose equivalent for any relevant stated period were not exceeded. Although the Commission emphasized in *ICRP Publication 2* that the rate of intake of a radionuclide could be varied, provided that the intake in any quarter was no greater than that resulting from continuous exposure to the appropriate MPC for 13 weeks, the concept of MPC has been misused to imply a maximum concentration in air or water that should never be exceeded under any circumstances. Similarly, MPBB has been misused to imply a maximum for the activity in the body, although it is evident that an intake in excess of MPBB for a radionuclide with a short residence time in the body would not result in the Commission's limits on dose being exceeded. For these and other reasons discussed below the concepts of MPC and MPBB are not used in this report.

As discussed in Chapter 4, SI quantities and units are used throughout this report. The special name for the SI unit of absorbed dose is the gray (Gy), of dose equivalent the sievert (Sv) and of activity the becquerel (Bq). Where a limit on dose equivalent recommended by the Commission is given in the text, the value in rem will be shown in parentheses.

Recommendations of the Commission have been developed over the years, first to avoid radiation-induced effects of early onset and later to minimize the possibility of radiation-induced cancer and hereditary disease. There are now sufficient data available about the effects of radiation for the Commission to give values for the risk per unit dose equivalent of radiation-induced fatal cancer in exposed people and of serious disease in their offspring (paras. 36–67, *ICRP Publication 26*).

It is intended that these values will be applied at the doses and dose rates of interest in radiological protection using the hypothesis that risks of these effects are linearly related to dose equivalent without threshold. Therefore, the risks of fatal cancer in an individual, group or population and of hereditary disease in their offspring is determined either by the total dose equivalent received by individuals, independent of dose-equivalent rate and the way dose equivalent is fractionated, or by the collective dose equivalent within the group or population exposed (paras. 22–24 *ICRP Publication 26*). Accordingly, the Commission proposes to minimize the risks of these diseases by a system of dose limitation (para. 12 *ICRP Publication 26*), the main principles of which are as follows:

(a) no practice shall be adopted unless its introduction produces a positive net benefit;

(b) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account;

(c) the dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.

This report concerns only the derivation of the secondary standards that limit the intake of radionuclides by workers in compliance with clause (c). It is recognized, however, that in many circumstances the cost-benefit analysis and judgment implied in clauses (a) and (b) might result in the average dose to the work-force being far below these limits.

The basic limits to be used for the control of occupational exposure are discussed in Chapter 2. For occupational exposure to radioactive materials the Commission believes that the time over which the dose equivalent should be integrated is a working life of 50 years as heretofore. In this report, the total dose equivalent in any tissue over the 50 years after intake of a radionuclide into the body is termed the Committed Dose Equivalent, H_{50}.

Several organs and tissues will be irradiated following the entry of a radionuclide into the body. In any year of practice, the values of H_{50} in all the organs of the body must be limited so that the resulting total risk of cancer and hereditary disease is less than or equal to the risk from irradiating the whole body uniformly to the appropriate annual dose-equivalent limit of 50 mSv (5 rem) recommended by the Commission in *ICRP Publication 26*. Additional constraints are imposed to prevent the occurrence of those effects which are produced only when some threshold of dose is exceeded. The method used to limit values of H_{50} is discussed in Chapter 2.

Secondary and derived limits for use in practice are discussed in Chapter 3. For each radionuclide in each of several chemical forms a secondary standard is given for the Annual Limit on Intake (ALI) either by ingestion or by inhalation. A Reference Man (*ICRP Publication 23*) receiving any such intake would be irradiated to the limit set by the Commission for each year of occupational exposure as described in the previous paragraph. Values are also given for the Derived Air Concentration (DAC) of each radioactive material. This is obtained by dividing the ALI by the volume of air inhaled by Reference Man in a working year. DACs are also derived for submersion of Reference Man in a cloud of a radioactive inert gas and in a cloud of elemental tritium. In such a case, a limit is imposed in any year of practice on the dose equivalents received by the organs and tissues of the body from external radiation.

The values of DAC are analogous to the values of MPC(air) derived in *ICRP Publication 2*. It is emphasized that values of DAC must always be used circumspectly. For inhalation of a radionuclide the overriding limit is the ALI and for submersion it is the time integral of the concentration of the radionuclide in air during any year of practice. No standard is developed here for a derived concentration in water because water is only one source of ingested material. The total activity ingested in any year should be controlled by use of the value of ALI for ingestion.

The general principles used to calculate H_{50} per unit intake of a radionuclide are described in Chapter 4. In this report, H_{50} in any target organ includes the dose from photons emitted by the radionuclide in other organs of the body as well as that from radiations arising from the radionuclide in the target organ itself. The total energy absorbed per unit mass in any target organ for each transformation of the radionuclide in any source organ, suitably weighted by the Quality Factor, is known as the Specific Effective Energy (SEE). H_{50} in any target organ is directly related to SEE and to the number of transformations, U, which occur in source organs during the 50 years after intake of the radionuclide. All the values given for H_{50} refer to unit intake of the stated radionuclide alone, but include the committed dose equivalent contributed by any daughter radionuclide produced from transformations of the parent radionuclide within the body. The principles of the methods used to calculate U for the parent radionuclide and U' etc. for daughters are also discussed in Chapter 4. It is acknowledged that any model used to describe the kinetics of a radionuclide and its daughters in the body will be an over-simplification of what could happen in practice. The models used in this report are adopted in the interests of providing a unified approach to the dosimetry of radionuclides in the body and are thought to be sufficiently accurate for the present purpose, which is to derive limits for the exposure of workers to radioactive materials.

Specific models for the routes of entry of radioactive materials into the body, namely the Respiratory System and the Gastrointestinal (GI) Tract, are described in Chapters 5 and 6 respectively. The model of the respiratory system is used to calculate the average committed dose equivalent in the lung, considered by the Commission for purposes of radiological protection as a composite tissue comprising the trachea and bronchi, the pulmonary region and its associated regional lymphoid tissues. The model is also used to calculate those fractions of the inhaled activity which are transferred either to body fluids or to the GI tract. Similarly, the model of the GI tract is used firstly to calculate the average committed dose equivalents in anatomically distinct sections of the tract, which are regarded as separate organs in the application of the Commission's basic limits, and secondly to calculate the fraction of ingested activity transferred to body fluids.

Chapter 7 describes the model used for dosimetry of radionuclides in bone. Committed dose equivalent is estimated for the relevant target tissues, identified as certain cells near bone surfaces and the red bone marrow.

Chapter 8 describes the methods used to derive a DAC for submersion of an individual in a radioactive, chemically inert gas or in elemental tritium. Arguments are presented to show that the limiting factor for tritium is irradiation of the lung, and, for inert gases, external irradiation of the body. It is shown that internal irradiation of the body from absorbed gas can be disregarded.

The relevant metabolic data required to calculate ALI and DAC for the radioisotopes of a number of elements are set out in pp. 63–115 of this report. They give data on daily intake, excretion, body content and distribution for the stable element taken from the report on Reference Man (*ICRP Publication 23*) and other sources. A description of the metabolism of compounds of the element is given, together with values for their absorption from the GI tract to the body fluids, their lung clearance classification as used in the dosimetric model of the respiratory system and models describing their retention in the whole body and relevant organs of adults. After each set of metabolic data for an element values are given for ALI and DAC for radioisotopes with radioactive half-life in excess of 10 min. The relevant dosimetric data for individual isotopes of the element are given in a Supplement to this report in the form of a computer print-out. They include information on the radioactive transformations of the radionuclide, values of SEE for a number of target organs from activities in different source organs, the number of transformations over 50 years in several source organs per unit intake by ingestion and inhalation of various chemical forms, corresponding values of H_{50} and of H_{50} weighted for sensitivity of the tissues to radiation-induced cancer and hereditary disease, and finally a table of values of ALI and DAC for occupational exposure. Further metabolic data on the elements and dosimetric data on their radioisotopes will be published as they become available.

Chapter 9 is concerned with limitations on the use of the data. It is stressed that the total dose equivalent which an individual has actually received and that to which he might be committed as a result of past exposure to radioactive materials is the primary factor determining his radiation status. The values of H_{50}, ALI and DAC given here or in the Supplement for radionuclides are criteria that are useful only for interpreting the occupational exposure of adults. Information is not given for other ages. The values of ALI are based on consideration of radiation dose alone; chemical toxicity has not been considered.

The Commission wishes it to be emphasized that the data given here are to be used only within the framework of its basic recommendations as described in *ICRP Publication 26*. Particular attention is drawn to para. 102 of those recommendations which implies that long-continued intakes of radionuclides at or near their ALIs by a considerable proportion of the workers would only be acceptable if a careful cost–benefit analysis had shown that the resultant risk would be justified. The models used in this report have been chosen, often conservatively, to derive values of ALI and DAC to ensure the protection of workers. The data provided herein should therefore not be used indiscriminately out of context, e.g. to estimate the risk of cancer in individual cases. The various assumptions made should be regarded as such and not as matters of established fact. Further research and data are required to improve the models which have been used.

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ICRP Publication 26, Recommendations of the International Commission on Radiological Protection. Pergamon Press, Oxford, 1977.

2. BASIC LIMITS FOR THE CONTROL OF INTERNAL DOSE

2.1. Introduction

In the decade or so since the Commission's former recommendations were published, more information has become available on the relation between absorbed doses of ionizing radiation and risks of biological effects. This new information enables the Commission to establish limits for exposure to ionizing radiation on a different basis than it has used heretofore (*ICRP Publication 26*). Two broad categories of radiation-induced effects are considered, namely,

(i) malignant and hereditary disease for which the probability of an effect occurring, rather than its severity, is regarded as a function of dose without threshold (stochastic effects), and

(ii) effects such as opacity of the lens and cosmetically unacceptable changes in the skin for which a threshold or pseudo-threshold of dose must be exceeded before the effect is induced (non-stochastic effects).

The Commission's recommendations are intended to prevent non-stochastic effects and to limit the occurrence of stochastic effects to an acceptable level.

2.2. Dose-Equivalent Limits for Occupational Exposure

The Commission believes that non-stochastic effects will be prevented by applying a dose-equivalent limit of 0.5 Sv (50 rem) in a year to all tissues except the lenses of the eyes, for which the Commission recommends a limit of 0.3 Sv (30 rem) in a year. These limits apply irrespective of whether the tissues are exposed singly or together with other organs, and they are intended to constrain exposures that fulfil the limitation on stochastic effects discussed below.

For stochastic effects the Commission's recommended system for limiting exposure is based on the principle that the limit on risk should be equal whether the whole body is irradiated uniformly or whether there is non-uniform irradiation. This condition will be met if

$$\sum w_T H_T \leq H_{wb} \qquad (2.1)$$

where w_T is a weighting factor representing the ratio of the stochastic risk resulting from tissue (T) to the total risk when the whole body is irradiated uniformly;

H_T is the dose equivalent received by tissue (T), and

H_{wb} is the stochastic dose-equivalent limit for uniform irradiation of the whole body.

For occupational exposure the Commission recommends the value 50 mSv (5 rem) in any year for H_{wb} and the values of w_T shown in Table 2.1. The values are recommended as appropriate for the protection of any worker, independent of age or sex (para. 104–106, *ICRP Publication 26*).

The value of w_T shown for bone surfaces relates to endosteal cells and to the epithelium on bone surfaces (Chapter 7). The value of w_T for the remainder of tissues requires further clarification. For reasons stated by the Commission in para. 105, *ICRP Publication 26*, a value of w_T of 0.06 is applicable to each of the five organs or tissues of this remainder receiving the greatest dose equivalents and the exposure of all other tissues in this group is neglected.

Table 2.1. Weighting factors recommended by the Commission for stochastic risks

Organ or tissue	w_T
Gonads	0.25
Breast	0.15
Red bone marrow	0.12
Lung	0.12
Thyroid	0.03
Bone surfaces	0.03
Remainder	0.30

Because of their very low sensitivity to cancer induction, skin and lens (paras. 61–64, *ICRP Publication 26*) are not considered as part of remainder tissue for limiting stochastic effects. When the gastrointestinal tract is irradiated, the stomach, small intestine, upper large intestine and lower large intestine are considered as four separate organs.

2.3. Limits for the Intake of Radioactive Materials by Workers

The estimates of risk of radiation-induced cancer and hereditary disease on which the Commission's dose-equivalent limits for stochastic effects are based were made using the hypothesis that risk of an effect is linearly related to dose equivalent. Therefore, it is the total dose equivalent averaged throughout any organ or tissue, independently of the time over which that dose equivalent is delivered, which determines the degree of effect in that tissue. With regard to limits on the intake of a radioactive material into the body, the Commission has reconsidered the question of the time over which this total dose equivalent should be integrated and has concluded that the period of 50 years used heretofore is appropriate for an occupational lifetime. The total dose equivalent in any tissue over the 50 years after intake of a radionuclide into the body is termed the Committed Dose Equivalent, H_{50}. It is emphasized that this is the dose equivalent which a Reference Man is assumed to receive if he lives for 50 years after his intake of the radioactive material and if no steps are taken to accelerate the removal of the radionuclide from his body.

Therefore, in order to meet the Commission's basic limits for the exposure of workers, the intakes of radioactive materials in any year must be limited to satisfy the following conditions

$$\sum_T w_T H_{50,T} \leq 0.05 \quad \text{Sv} \tag{2.2a}$$

and

$$H_{50,T} \leq 0.5 \quad \text{Sv} \tag{2.2b}$$

where w_T is the weighting factor shown in Table 2.1, and

$H_{50,T}$ (in Sv) is the total committed dose equivalent in tissue (T) resulting from intakes of radioactive materials from all sources during the year in question.

Relationship (2.2a) limits stochastic effects and (2.2b) non-stochastic effects, arising from intakes of radioactive materials. With regard to (2.2b), the limit for non-stochastic effects in any tissue is taken as 0.5 Sv (50 rem), since no case is known where lens opacity would be the factor limiting intake of radioactive materials. It might be the limiting factor when the body is irradiated from the exterior by submersion in a radioactive noble gas and values for the derived air concentration in such cases are discussed in Chapters 3 and 8.

2.4. Restrictions on the Rate of Intake of Radioactive Materials

The Commission believes it is sufficient to limit the intake of radioactive materials in any year to the recommended limits and does not recommend any further restrictions on the rate of intake, except in the case of occupational exposure of women of reproductive capacity and pregnant women as discussed in paras. 35, 115 and 116 of *ICRP Publication 26*.

Reference

ICRP Publication 26, Recommendations of the International Commission on Radiological Protection. Pergamon Press, Oxford, 1977.

3. SECONDARY AND DERIVED LIMITS FOR THE CONTROL OF INTERNAL DOSE

3.1. Reference Man

The standards for control of internal dose for workers are derived for an adult person of stated anatomical and physiological features which are defined in the report of the ICRP Task Group on Reference Man (*ICRP Publication 23*); see also Table 4.1 (Chapter 4). The transfer of radionuclides to blood following inhalation or ingestion are discussed in Chapters 5 and 6, which set out dosimetric models for the respiratory system and gastrointestinal tract respectively. The metabolic data for the various elements considered in this report include a description of their behaviour in the respiratory system and gastrointestinal tract following inhalation and ingestion and their partition and retention among the various body organs and tissues following entry to body fluids.

3.2. Committed Dose Equivalent (H_{50})

The committed dose equivalent (H_{50}) in a particular organ or tissue is the total dose equivalent to which that organ or tissue would be committed during the 50 years after intake of a radionuclide. Estimates of H_{50} per unit intake of a radionuclide are made by the methods described in Chapter 4, and values are given for a number of organs and tissues in the Supplement which gives dosimetric data for individual radionuclides. These estimates are based on the characteristics of Reference Man.

3.3. Annual Limit on Intake (ALI)

The annual limit on intake (ALI) of a radionuclide is a secondary limit designed to meet the basic limits for occupational exposure recommended by the Commission and is derived from relationships (2.2a) and (2.2b) in Chapter 2 as follows. ALI is the greatest value of the annual intake I which satisfies both of the following inequalities

$$I \sum_T w_T(H_{50,T} \text{ per unit intake}) \leq 0.05 \quad \text{Sv} \qquad (3.1a)$$

$$I\,(H_{50,T} \text{ per unit intake}) \leq 0.5 \quad \text{Sv} \qquad (3.1b)$$

where I (in Bq) is the annual intake of the specified radionuclide either by ingestion or inhalation;

w_T is the weighting factor for tissue (T) and has the values shown in Section 2 of Chapter 2, and

$H_{50,T}$ per unit intake (in Sv Bq^{-1}) is the committed dose equivalent in tissue (T) from the intake of unit activity of the radionuclide by the specified route.

3.3.1. *Application of annual limits on intake*

(a) Values of ALI are estimated for exposure, both by ingestion and inhalation, to the specified radionuclide. Any daughter radionuclides produced in the body after intake of the specified radionuclide are taken into account. When the intake consists of a mixture of radionuclides, and/or exposure occurs both by ingestion and inhalation, the values of ALI do not directly apply. In all such cases it is recommended that intakes in any one year should be controlled so that the equations set out in Section 2.3 of Chapter 2, relating to the committed dose equivalent from all sources, are satisfied. A more complete statement on the method recommended to control exposure to mixed sources of radioactive materials is given in Chapter 9.

(b) Values of ALI and of H_{50} per unit intake are intended for use in the control of occupational exposure and are based on the parameters of a Reference Man. However, when there is reason to believe that a particular individual has taken in more than the ALI, and it is thought necessary to estimate the resulting committed dose equivalent, it is recommended that his age and known biological parameters should be taken into account as far as is practicable.

3.4. Derived Air Concentration (DAC)

Formerly the Commission recommended maximum permissible concentrations in air and water as guides to the control of exposure to radionuclides. Although intended to control exposure over prolonged periods of one-quarter of a year or more the values have often been misused to infer an over-exposure even when they have been exceeded only over a shorter period.

The Commission wishes to emphasize that the limit for inhalation of a radionuclide is the appropriate ALI. The concentration of a radionuclide in air during any year is limited as follows

$$\int C(t)\, B(t)\, \mathrm{d}t \leq \mathrm{ALI} \quad \mathrm{Bq} \tag{3.2}$$

where at any time t,

$C(t)$ (in Bq m^{-3}) is the concentration of the radionuclide in air;

$B(t)$ (in m^3 per unit time) is the volume of air breathed by the worker per unit time, and the limits on integration are over a working year.

The value of $B(t)$ depends on the type of work being performed and for heavy work it could be more than twice the reference value for "light activity" given in *ICRP Publication 23*.

For convenience, the Commission recommends values of derived air concentration (DAC). The DAC for any radionuclide is defined as that concentration in air (Bq m^{-3}) which, if breathed by Reference Man for a working year of 2 000 h (50 weeks at 40 h per week) under conditions of "light activity", would result in the ALI by inhalation.

$$\mathrm{DAC} = \mathrm{ALI}/(2\,000 \times 60 \times 0.02)$$

$$= \mathrm{ALI}/2.4 \times 10^3 \quad \mathrm{Bq\ m^{-3}} \tag{3.3}$$

where 0.02 m^3 is the volume of air breathed at work by Reference Man per minute under conditions of "light activity" (*ICRP Publication 23*).

In the unlikely event of a person being exposed continuously to a DAC, and breathing air at a rate which is on average greater than 0.02 m^3 per min, the activity inhaled in a working year would be more than the ALI. In this respect, it is emphasized that the ALI is the overriding limit and the derived limit DAC should always be used circumspectly.